Srinivasan, Sharda and Srinivasa Rangnathan. 2004. *India's Legendry Wootz Steel*. Bangalore: Tata Steel. Pp. 146. Price not mentioned.

The legendry Wootz steel of ancient India has remained shrouded in mystery. It had marvellous qualities of hardness and rust resistance and was given the enigmatic names of Wootz and Damascene steel. Its popularity, world fame and global demand goes back to I millennium BCE. The British hated it as a rival steel industry and tried even to destroy it. So Wootz is not only a metallurgical marvel but represents a peak of Indian technology. There are scattered accounts of Wootz but so far there was no book written on such a great technological innovation of India by an Indian author. Now we have a book written by experts, yet done in a popular style. Both Srinavasan and Ranganathan are well known metallurgists. In addition, Srinivasan has a PhD in archaeology from London University. The multidisciplinary background of the authors has amply enriched the text of the book. The illustrations add spice to the text and are very well done.

The book discusses various aspects of the Wootz steel in ten chapters. In Chapter 2, they give a very useful discussion of the three stages of human technological evolution. The last two chapters discuss the metallurgical aspects and technical data, but in a style which does not frighten a layman. After all writing about the technology of Wootz can not be expected to be a very interesting theme for a layman. But the beauty of the book lies in its use of simple and interesting language. I am sure it has become a fascinating read for the layman too. We do need such books on Indian History of Science and Technology. The authors thus have rendered a great service in popularising metallurgy as also History of Science and Technology. Besides, the book gives an updated story of Indian steel industry.

Let us briefly summarise the contents of the different chapters.

Summary of Chapters

In the first chapter the authors introduce iron technology in a historical perspective**.** They rightly claim that the name Wootz is related to the glorious past of India in iron and steel manufacture. In ancient times India was the nodal centre for steel production. At that time the fame of India's Wootz steel was well recognised around the world. It is interesting to note that one of the precious gifts accepted by Alexander from India was the Wootz steel. This fact reflects the high status of Indian steel. Another remarkable example of the Indian Wootz steel is the 1600 years old Delhi iron pillar. It is the hallmark of Indian steel situated in the Qutb Minar complex. It is the earliest and the largest surviving example of iron forging in the world. It was built between *ca*. 400-420 (Gupta Era). This iron pillar has attracted the attention of archaeologists and metallurgists all over the world for its excellent anti-corrosive property. This pillar is generally known as 'the rust-less wonder', because even after centuries there is no sign of rust on it. At that time India was also famous for sword smithy. A sword smith of Thanjavur was known for his mastery in sword making. The best example of Indian sword smithy is the famous 'Sword of Tipu Sultan' (now in the personal collection of the tycoon Vijay Mallya).

Apart from its historical significance, the Wootz steel has also carved a niche for itself in the annals of science. Srinivasan and Rangnathan inform us that the best known scientists of the time such as Michael Faraday, Jean Robert Brant and Paul Anossoff investigated and characterized it. In fact, the Wootz steel paved the way for the development of the 19th century metallurgy and induced the production of alloy steels.

What is Wootz after all? Srinivasan and Rangnathan explain that Wootz is a type of high grade steel and more than two millennia ago the steel made in South India was known by a similar name. The term Wootz was coined by the European travellers from the 17th century onwards. They came across the making of steel by crucible process in South India (in the present states of Tamil Nadu, Andhra Pradesh and Karnataka). In Kannada language the word used for steel is *ukku* and Wootz is the Anglicisation of the word *ukku*. The area of Hyderabad, formerly Golkunda, was the most reputed area for the production of Wootz. In south India the Wootz ingots were produced and exported to various places. The Wootz steel was made by the crucible steel process over a fairly vast area of South India as a semi-industrial enterprise. Shipments of tons of thousands of the Wootz ingots were being exported to many places all over the world.

The authors rightly complain that although Wootz was such an important material in the history of metals, it has not received proper emphasis so far. There is no single book available by Indian authors on this subject but much has been written about Indian Wootz steel by the travellers from Italy, France and England. We can trace the fame of Indian Wootz steel in the following words of Arab Edrisi (12th century), '*The Hindus excelled in the manufacture of iron and it is impossible to find anything to surpass the edge from Hindwani or Indian steel'*.

In the early decades of the 20th Century the fame of Wootz steel began to decline, though the Indian Wootz steel reigned supreme until a few centuries ago. Colonization by the British led to its near extinction. It was J. N. Tata who revived the dying steel industry. His efforts led to the setting up of Tata Steel plant (earlier known as TISCO) in 1907. Sir M. Visvesvaraya started the Mysore Iron Works in 1918. The Twenty First century has seen many new initiatives.

The authors have made it clear that the Wootz steel was a remarkable contribution of India to global sciences, as it was a precursor to the modern alloy manufacturing techniques. From the point of technology its quality is still incomparable.

In Chapter 2, the authors give the archaeological background of the Three Ages of Civilization: The Stone, Bronze, and Iron Ages.

The Stone Age refers to the time, before the use of metals, when most tools and weapons were made of stone. The Stone Age occurred at different times in different parts of the world. In Europe and Asia, it began about two million years ago, (in Africa the earliest tools go back beyond 4 million years). In the most advanced parts of the Middle-East and South-East Asia it ended about 6000 BC, but it lingered until 4000 BC in other parts of the world. In the Chalcolithic Age, copper was discovered as a new material. The Copper Age started from 6000 BC and lasted till 1000 BC, eventually giving way to the Bronze Age.

The authors explain that in the ancient past, usually those metals were used which occur either in a natural state or in an elemental state. Then gradually the use of other metals started which could be easily extracted or smelted. However, smelting was mastered in later periods because it was more difficult and specialised than extraction.

The Bronze Age (3000 BC-1500 BC) refers to the time before the introduction of iron, when most of the tools and weapons were made of bronze. Bronze came into use at different times in different parts of the world. Early evidence of copper smelting comes from parts of Israel, Jordan, Egypt, and the Middle-East between fourth to third millennium BC. Copper artefacts of about sixth millennium BC were also reported from the pre-Indus valley sites of Baluchistan.

After the Bronze Age came the Iron Age. The authors inform us that one of the earliest known man- made iron object apparently comes from the great pyramid of Giza (Waldbaum in *The Coming of the Age of Iron* 1980:73-74 however has reported many pre-3000 BCE iron finds from West Asia). The Hittite kingdom of the mid-second millennium BC was one of the early iron producing centers. The Hittite records show that they were aware of two different types of iron –the black one, which is said to have fallen from heaven (meteoritic) and the other which is extracted from the earth. It has generally been assumed that Hittites were Aryan speaking tribes and they had the monopoly on iron production. Their knowledge eventually diffused to various parts of the world.

The authors briefly explain the chemistry of Iron. Iron, a metallic element with symbol Fe, is the fourth most widely distributed element forming about 5% of the earth's crust. Iron is generally found as iron ore. The common iron ores are haematite (Fe_2O_3), magnetite (Fe_3O_4), goethite ($HFeO_2$) and limonite [$FeO(OH)n.H_2O$]. The earth's mantle also contains iron in the form of iron and magnesium silicates. Besides this a little iron occurs as native iron in limited areas known as telluric iron. There are many examples of meteorites consisting entirely of iron, known as siderites.

Linguistic evidence suggests that the Egyptians were using meteoritic iron by the late third millennium BC. There are references to iron from heaven which implies meteoritic iron. Meteoritic iron was also exploited by the North American Indians to make weapons.

Pure iron melts at 1536^{o}C and this high temperature was hard to achieve in ancient times hence iron was generally produced and worked upon in the solid state. Only in China, it was produced in the liquid state as cast iron. Bloomery iron is the first product of smelting. It is a solid, spongy mixture of iron and slag. Slag is a glossy substance that results from mineral impurities in iron, which reacts with lime or limestone. Lime or limestone is usually added to the furnace charge. Inclusions of slag make the bloom brittle while cold, but malleable while above 250^{0} C.

In this chapter, the authors also briefly discuss the iron metallurgy as practiced in India, China and Japan.

Iron has been used in India from about late second millennium BC (In fact, some sites in U.P give older dates for the use of iron). The forging of wrought iron reached its peak in the first millennium AD. Francis Buchanan and Verrier Elwin have reported iron smelting furnaces in India in the eighteenth to early twentieth century. A tribe known as the *Agarias* specialized in iron smelting and this art was kept a tribal secret for generations. As already mentioned the earliest forged iron in the world is the famous iron pillar at a New Delhi dated by the inscription to the Gupta period (*ca* 400 CE). It is about 7 meter high and its weight is about 6 tonnes. Apart from the dimensions, another remarkable aspect of this pillar is the absence of corrosion. There are other well-preserved monumental iron pillars such as the iron pillar at Kodachadri in coastal Karnataka and one in Dhar in central India. The iron beams of Konark temple are also in good condition.

The cast iron was produced earliest in China in small blast furnaces. The cast iron production requires higher temperatures and more reducing conditions, which probably gave rise to furnaces. Though cast iron has a high carbon content which makes it fairly unworkable alloy with poor strength, it has the lowest melting point which makes it useful for the various purposes. By the early Christian era cast iron was used in China on a very large scale for making tools, weapons, vessels, and utensils. The Tatara iron has been produced in Japan for about 1000 years. It was introduced from Korea in the second half of the sixth century CE. The use of iron sand powder is characteristic of this process. Now this process is almost extinct. This was the main source for making the Japanese sword.

Sword production is covered by Chapter 3. Till the advent of iron, sword making was not very common. Soon smiths became aware of the fact that if iron was heated in charcoal fire for a long time and cooled in water or quenched, it acquired some improved qualities. This laid the foundation of steel making. After that the forging of sword started. The sword remained an important weapon for more than a millennium. In ancient times India was reputed for making quality swords. The blade is the sharp edged part often with a pointed tip and handle is the upper part of sword which can be made of various materials ranging from jade to bejewelled cast metal. There are several types of swords like the rapier (European), samurai (Japan), *jian* and *dao* (Chinese), *shamshir* (Persian), *katar* (Indian) etc.

The crucible steel making stage covers the time span of 300 BC to 1856 CE. Whereas, modern Steel Age begins with the discovery of Bessemer's process, it is a process of transforming cast iron into malleable steel by de-oxidation process. Henry Bessemer took out a patent for the above process so it was named after him. Then a British metallurgist Robert Mushet improved upon Henry's process. India saw the decline of iron smelting under the British colonial rule. But as already pointed out, in the nineteenth century J. N. Tata revived it by setting up Tata Steel Plant in 1907. Now with many refinements India again has started producing steel on a global scale.

The authors explain that steel is an alloy of wrought iron and carbon. Initially steel had to be produced in two steps. The first was to add carbon to the wrought iron which came to be called the cementation process or carburization. The second step is known as decarburization, to remove carbon from the cast iron. Carburization is also known as case hardening/forge hardening. In ancient times wrought iron could be carburized by heating it in charcoal fire for a long time. This is a slow process which takes several days, because this reaction takes place in solid state. The process results in a steel of intermediate composition and it is then evened out by hammering, annealing and folding many times. This significantly decreases the carbon content away from the exposed surface. Decarburization dilutes the carbon content of cast iron. This process breaks cast iron into small lumps and is followed by heating the lumps at high temperature in an oxidizing air blast. The iron melts and carbon blows out as carbon-di-oxide and the decarburized iron droplets sink to form a bloom below the hot zone.

It is generally believed that the above mentioned process, which is also known as crucible steel making, was developed primarily in India leading to the Wootz steel. It is a process that reflects the first age of steel.

Then came the modern age, with the invention of Bessemer's process in which molten cast iron was contained in a tank and hot air was blown. The oxygen reacts violently with carbon as CO_2 is liberated. This lowers the carbon constituents of cast iron. The Wootz steel led to the making of the phase diagram of iron and carbon by Sir William Robers -Austen in 1893. This was the very first establishment of phase diagram of an alloy which was the precursor to the invention of other alloys of iron.

The cream of the book is in Chapter 4 as it tells the story of the Wootz and Damascus steel. The authors divide the development of Wootz and Damascus steel into three parts-

(i) 300BCE to 1500 CE
(ii) 16^{th} to early 20^{th} century CE
(iii) Later half of the 20^{th} century CE

The earliest accounts related to the use of iron in Ancient India, are attributed to the Greek historian, Herodotus, who wrote about the battle of Thermopylae (*ca* 480 CE), in which he mentioned that Indians were the part of the Persian army in this battle and they had used cane arrows with iron tips. Another example is of Alexander the Great who was presented with a hundred talents of 'ferrum candidum', or "bright iron". A well known account from Roman source is by the elder Pliny (1^{st} century BCE –to 1^{st} Century CE) in his *Natural History, the Encyclopaedia of the Roman Empire* in which he mentioned the export of iron ingots from the 'Seres', in South India. This is also authenticated by archaeological excavations and Tamil literature. The *Periplus of the Erythrean Sea*, a Roman travelogue and the account of Alexandrian alchemist also suggest the iron making by crucible process in India.

The authors think that the Arabic sources provide the most significant historical accounts that point towards the primacy of Indian iron and steel in ancient times. The Arab accounts also reveal the fame of ‘Teling’ steel, which can be taken to refer to the region of Telengana in Andhra Pradesh in Southern India. However, Golkunda region was the nodal centre for the export of Wootz steel to West Asia. The prophet Muhammad is also said to have had a sword made of Hindwani steel.

The terms *bulat* and *Ondanique* were used for the Wootz steel. Generally it’s a mistaken notion that Damascus steel was manufactured in Syria but it is the fame of swords manufactured at the great Syrian capital of Damascus of *poulad/ bulat* steel which has given the Wootz steel the name Damask or Damascus steel. The Wootz steel was known as *poulad* in west Asia. There developed an industry of weapons and armament of this steel. The early medieval period trade contacts of the Syrian towns with India, apart from other countries, seem to have promoted the production of Damascus swords. Damascus, the great Syrian capital, is said to have widely traded with the Indian town of Koch, in which a lot of metal shops existed.

Russians were also familiar with the Wootz steel. The works of celebrated Russian writers Alexander Pushkin (1799-1837) and Mikhail Lermontov show that they were familiar with the Wootz. In Russia it was known as *bulat*. In the early 19^{th} century Muslims dominated Chechanya in the former Soviet Union and shared cultural links with the oriental Islamic Central Asia and Turkey. The influence of *bulat* or Damascus steel was so high in Chechanya that it became a part of Chechan name conveying the attributes of a ‘man of steel’! Such evocative Chechan names range from shchokbulat (snow leopard bulat), hasbulat (beautiful bulat), sambulat (watchful bulat), dzambulat (battle axe bulat), arbulat (black bulat) etc. Ondanique is another European term for Hindwani steel used by the Arabs.

In Chapter 5 the authors discuss the Wootz Steel and Indian Armoury. From the mid-seventeenth century onwards, there are numerous eye-witness accounts of European travellers to the Indian subcontinent, which describe the production of steel by crucible process spread over different parts of South India. According to Holland, crucible is something like a large pear about 5” long and 3” in diameter at the widest part because it is somewhat conical in shape. At that time Indian Wootz was so famous that it was exported to all over the world and it is generally believed that the Indian Wootz was made solely for export but there are rich traditions of Indian armoury too. The *Ain-i-Akbari*, by Abul Fazal is a major work on the arsenal making during Akbar’s time. It also gives an idea about personal swords of Akbar.

In the 1600s and 1700s the trading firms of the Dutch, the French, and the British East India Company were formed to take advantage of the lucrative trade opportunities with India. But soon they gained political control. Many efforts were made to check them. Tipu Sultan, Rani of Jhansi, Rani Chennama etc. are the ones who resisted the British hegemony with their swords. And the fame of the swords of Tipu Sultan has its own place, as these remain in high demand and keep turning up at auctions abroad. During the reign of Tipu Sultan the art of metallurgy for fashioning rockets was mastered, which could reach 2.5 Km with a fair degree of accuracy. Tipu's rocket corps had 5000 soldiers. Several Indian rockets were taken to Britain to understand the technology of Indian products which were technologically superior to western equivalents, and this was recognized by everyone. The British were also familiar with the superior quality of Indian swords. That is why following the Indian mutiny in 1857; the British ordered the destruction of all the Wootz swords. Even a special shearing machine was developed to destroy the Damascus blades. It is also said that often the shearing blades of the machine themselves got cut by the tough Wootz swords, and the British then had to devise a protective measure for their shearing machines!

The authors refer to various foreigners' accounts of export of Indian steel of over 10,000 pounds in the mid-17th century. By the 1660s the Dutch also became involved in developing the iron industry in the Golconda delta of Andhra Pradesh.

The authors tell us that according to Buchanan's account the crucibles were made by finely churning the necessary ingredients like clay and charcoal under the feet of stomping bullocks. The crucibles themselves were conical and made of unbaked clay and were then loaded with iron along with pieces of tangerine wood. These crucibles were then fitted into a sunken pit filled with ash to constitute the furnace and heated by using bellows for at least 6 hours. After that iron pieces were recovered from the crucibles and hammered under heat into small bars. The region of Salem and Tanjavur in central Tamil Nadu were famous for iron mining and iron smithy. In his accounts on the Tanjavur armoury of the 1870s, Major M. J. Walhouse has mentioned a highly reputed ironsmith from Salem.

The authors explain that there is a misconception that Damuscus swords were the result of the West Asian tradition and that only ingots were made in India. They inform us that there are numerous examples of fine Damascus swords with the characteristic damask pattern from Mughal India, the armoury of Golkunda and Hyderabad's Nizams, Tipu Sultan's armoury, Ranjit Singh's armoury, Rajput, Tanjavur and Maratha armouries. The Wootz or Damascus steel was made at numerous centers all around the sub-continent like Gwalior, Tanjavur, Lahore, Agra, Jaipur, Amritsar, Golkunda, Mysore etc. Among these Golkunda and Mysore were the highly reputed ones. The craft of making Wootz steel died out sometime in the 19^{th} century and has not survived today at any of these centers.

In Chapter 6, the authors emphasise the importance of the impact of the fame of Wootz on Europe after the 16^{th} Century. They attribute the credit for industrial revolution in the 16^{th} century to early 20^{th} century to the fame of Wootz steel and Damascus blades. The Wootz brought a dramatic change in the availability of an advanced industrial material in the form of steel. The scientific revolution primarily occurred in England.

The steel produced by the natives of India astonished their British masters. This laid the foundation of scientific studies in Europe and eventually led to the discovery of basic principles of material science. The 18th, 19^{th} and early 20^{th} centuries saw an experimental period of European interest in trying to understand the nature and properties of the Wootz steel. The Wootz attracted the attention of some of the best known scientists like Michael Faraday, James Stodart and Breant. And the experiments to replicate Wootz and to understand its properties not only gave rise to other alloys but also helped identify other elements of the periodic table such as rhodium, osmium, palladium, uranium, platinum etc. In 1962 Panseri was the first to point out that the Damascus steel was hypereutectoid steel with spheroidised carbides having carbon content between 1.2 and 1.8 %. Stodart succeeded in forging Wootz steel and he also used it in his cutlery business. Faraday and Stodart joined hands and studied Wootz together during 1819-1822. Anossof is considered to be the first person in Europe to have succeeded in making blades of Damascus steel. John Robert Breant did several experiments and came to the conclusion that the properties of Damascus steel were due to ‘carburized steel’. In a seminal paper he distinguished the micro constituents of steel, now termed as cementite, ferrite and austenite. He also demonstrated the change in texture with variations in composition, temperature, and mechanical deformation.

In Chapter 7 the authors discuss the American interest in the Wootz in the Twentieth Century. They inform us that the famous archaeometallurgist Cyril Stanley Smith played a major role in reviving the waning interest in the Wootz and Damascus steel. In his landmark book *The Search for Structure* he tried to explain how the artistic accomplishments of the ancient world and the Orient played their part in kindling early interest in metallographic and material science. He also revealed that steel was not commercially melted in Europe until the mid 18^{th} century and that even this was a ‘texture less tool’ steel with no more than 0.8-1% carbon. They also discuss the role of others like Sherby and Wadesworth at Stanford University in developing super elastic ferrous metals. The studies by Sherby and Wadeswort in 1990s indicated that UHCS (Ultra High Carbon Steel) with a carbon content of around 1.5% exhibited superelastic properties. When their results were presented, a member in the audience pointed out that their composition matched that of Wootz steel. This led Sherby and Wadesworth to their research into the study of Damascus steel.

Materials which exhibit superelasticity are described as advanced materials. So, we can say Wootz too can be classified as an advanced material of the ancient world. Another reputed American team led by Verhovean and the blacksmith Alfred Pendray made numerous attempts to reinvent Damascus steel and blades with many experiments based on historical studies and the composition of Wootz ingots. Verhovean with Alfred Pendray made extraordinary efforts to understand the Damasked patterns on the blades. Verhovean said that 0.003% vanadium is effective in producing iron carbide banding of 'watered steel' pattern. Another explanation that has been put forth about banding mechanism is the presence of phosphorus. Alfred Pendray and Verhovean have outlined some simple steps to make Wootz and Damascus blades. They recommend the use of high purity iron, charcoal, glass chips and green leaves and Soral iron (vanadium impurities) to be loaded in the crucible. Ric Fullar also demonstrated traditional making of Damascus blades at the Smithsonian Institute Folklore Festival in 2002.

The authors also tell us that today's patent for UHCS (Ultra High Carbon Steel) in reality is influenced by an ancient technique which was developed in India many centuries ago rather than being a modern innovation.

In Chapter 8 the authors discuss the imitation of true Damascus blades made in parts of Far East, such as Korea, China, Japan and Indonesia and some parts of Europe. The evolution of these blades is perhaps a mutual influence due to trade and travel. This technique is also known as pattern welding. Although this technique has created beautiful designs on the blades, it died out around the 10^{th} century, though the western interest in pattern-welded blades rose again during the crusades of the 12^{th}, 13^{th} and 14^{th} centuries. Pattern welding consisted of folding or twisting of the layers of steel into a finely laminated structure. They go in some detail about sword making industry in Japan, Korea, Indonesia, and Spain.

The West has used and expropriated several Indian innovations. Similarly, though the Wootz or UHCS, in modern terms is an Indian invention but modern research on UHCS has sought protection under intellectual property rights. In January 1992 Verhoeven and Pandrey filed a US patent for a method of making Damascus blades.

The authors emphasise that the need of the hour is to wake up the Indian Government to stop further piracy of such innovations.

In Chapter 9 the authors discuss the recent attempts to study Archeometallurgy of Wootz in India. They tell us that Kodumandal, near Coimbatore in Tamil Nadu is the earliest site with some evidence of crucible steel making. K. Rajan of Tamil University, Thanjavur uncovered a substantial megalithic burial- cum –habitation site dating back to the 3rd century BC. Here a set of 13 furnaces was uncovered. Inside one of the small furnaces a vitrified crucible fragment was found. The shape and the fabric of the crucible were similar to the crucibles found in South Asia. The scanning electron microscopy and electron probe analysis show that 70% iron was found in the crucible fabric. Markings in the crucibles suggested that here the wrought iron was first carburized to high-carbon steel by packing it inside crucibles with carbonaceous materials and firing it over long firing cycles. In an adjacent canal, debris of crucible steel production was also reported. At the dump of the mound thousands of broken crucible fragments were strewn all around. The debris and bits of slag were found not only on the dump but scattered all the way around the perimeter of the area and into the canal area.

At some places the cross-sections of various fragments of the crucibles show that the inner lining of the crucibles had rusty metallic remnants, and a lid fragment. In the glassy matrix of the vitrified crucible fragments there were found a few metallic globules ranging in size from 10 to 100 microns. The microstructure of these globules is similar to the structure of high-carbon steel of about 1.3-1.5% carbon. Kodumanal also throws light on the Wootz steel production. Here, A. Sundara has reported a sample of pre-Christian era with 1.7% carbon which is comparable to the composition of Wootz steel.

Thelma Lowe's extensive survey in the region of Andhra Pradesh has identified nearly fifteen sites for crucible steel production in the area of Konasamudram and Nizamabad in Andhra Pradesh. She had surveyed an astonishingly large area of 6000 square km. falling between 72 km E-W and 110 km N-S. Within this area she identified, mapped, and sampled as many as 94 deposits of iron smelting debris located on 74 production sites. Though these crucible steel sites have not yet been dated through archaeological excavation, but Lowe has pointed that this area traditionally had an iron industry for smelting of laterite and magnetite ores that dated back to the first millennium BC. Thelma Lowe together with Gareth Thomas indicate that the historical Deccani crucible fabric could be characterized in modern terms as a high-performance refractory known as a mullite fiber-reinforced ceramic composite. Ananda Coomaswamy and Gill Juleff too have reported such sites in Sri

Lanka.

Today, the skills of making Wootz steel are completely lost in India with no traces left behind, except from the debris of crucibles strewn randomly over many parts of South India, though rural black-smithy is still being practiced quite widely all over India to make agricultural tools, ploughshares, utensils etc.

The authors update the latest advances in technology in Chapter 10 and point out how they help us understand the past technology much better. So far various techniques like optical microscope and mechanical testing etc. revealed various unexpected facts and gave rise to Archaeometallurgy. As scientific advances continue the authors expect more knowledge of ancient metals with the aid of two recent developments: nanotechnology and quantum mechanics. (Nanometre is the one billionth of a metre thus nanotechnology refers to materials which are close to the molecules in the length scale). Damascus steel is also the result of a kind of nanotechnology. This is a kind of alchemy where the optical property of a metal is changed by varying its size. When the size gets to nanometre level, another effect takes place which is called quantum effect. With the help of these two techniques now scientists are able to describe Damascus steel in modern terms. In a Damascus steel sample the investigators found high density nanowires which revealed lattice plans of cementite.

The conventional wisdom for the metallic materials is that as strength goes up ductility and concomitant toughness are reduced. Then how the ancient India metallurgist produced steel with multiple properties? The authors inform us that UHC (Ultra High Carbon) imparted the necessary strength. Because in the usual microstructure of steel cementite will occur at grain boundaries and lead to embrittlement. The super-elastic forging does not allow the embrittlement as it breaks up the cementite bond. This enhances both ductility and toughness. Besides this the German scientists speculate that nanowires are also responsible for growth kinetics of the microstructure and act as obstacles for dislocation as well as crack propagation.

The authors further explain that Quantum mechanism offers another insight into the structure of Damascus sword. This may be called ‘solidification design’. With variations in temperature various changes take place which are termed as transformation design. When the particle size is reduced to 0.1μm scale the design enters the micromechanics regime. Beyond this size the nanoscopic level begins but further experiments are yet to be carried out to reveal the exact technology. Indeed the ancient sword makers or the metal workers were accidental nanotechnologists.

That's why the advanced material of Damascus steel still continues to astonish everybody. Thus Wootz has an enduring significance even in this modern age of silicon, nanomaterial and quantum mechanics.

To sum, Srinivasan and Ranganathan have produced a book which truly bridges the gulf between the Two Cultures. It smoothly covers prehistory to modern history and brings up the story of steel right up to the post Independence growth of steel industry in India. It brings out the marvels of Wootz technology which we can only understand now with the advances in nanotechnology and Quantum Mechanics. It builds the story of Wootz from a variety of sources: travelogues, old texts, archaeological evidence. They have truly created a very interesting book even on such a dull theme as iron! For this great effort of Srinivasan and Ranganathan, scholars and laymen interested in archaeology, archaeometallurgy, History of Science and Technology and the specific story of the Wootz steel will be beholden.

In covering a vast span of time, from Stone to Iron Ages, some inaccuracies in timescales have crept in. It would have added to the value of the book if the recent surprising discoveries of early iron discovered at various sites in UP, Raja-Kiran-Ka- Tila and Malhar could also have been commented upon. Raja-Kiran-Ka-Tila has given C-14 dates ranging from 1400-1600 BCE (PRL-2045, -2046, -2049) and Malhar goes even up to 2000 BCE (BS-1590, BS-1593, -1623).

The book is a must for all those interested in archaeology, archaeometallurgy, History of Science and Technology, and of course in the history of the enigmatic Wootz steel.